AERONAUTICS.

TECHNICAL REPORT

OF THE

ADVISORY COMMITTEE FOR AERONAUTICS

FOR THE YEAR 1918-19.

(With APPENDICES.)

VOL I.

General Questions, Airships and Model Aeroplane Research.

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MEMBERS OF THE COMMITTEE,

March, 1919.

The Right Honourable Lord RAYLEIGH, O.M., F.R.S. (President).
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Sir NAPIER SHAW, F.R.S.

Secretary, Mr. F. J. Selby,
Assistant Secretary, Mr. J. L. Nayler.

National Physical Laboratory,
Teddington,
Middlesex.

Since this report was in type the Committee have learned with the deepest regret of the death of their President, Lord Rayleigh.

They desire to put on record their sense of the great loss sustained by English Science, and their high appreciation of the value of his labours for the advancement of aeronautics.

The methods of research adopted initially owe their value in no small degree to his insight, while his conduct of the business as President has added greatly to the success of their work and to the importance of the results attained.

REPORT FOR THE YEAR 1918-19.

To the Right Honourable WINSTON CHURCHILL, M.P.,
Secretary of State for Air.

SIR,

The Advisory Committee for Aeronautics begs to submit its report for the year 1918–19.

Previous to the War it was the practice to summarize briefly in the report the main features of the work carried out under the control of the Committee during the year under review, and to indicate the more important advances made as the result of the investigations and researches conducted on models and on full-scale aircraft. While the War continued it was necessary to avoid including in the report any information which could be of value to the enemy; it appears now desirable to revert to the earlier practice, and it may be useful to attempt to give a brief account of the progress made in aeronautical research since the year 1914, and of its application in practice. This has been done in a supplement to the present report; some of the more important features of the work are indicated in a more general manner below. The supplement is followed by a table of notable performances of British aeroplanes, seaplanes, and airships, kindly furnished by the Director of Research for publication in this Report. It is thought that this will be found of special interest.

A number of changes in the *personnel* of the Committee have taken place since 1914. In that year the representatives of the Admiralty and of the War Office serving on the Committee were Commodore Murray F. Sueter and Major-General Sir David Henderson. In the following year Mr., now Sir, E. H. Tennyson d'Eyncourt, Director of Naval Construction, was added to the Committee. In 1916, Dr., now Sir, Dugald Clerk was appointed a member, and Mr., now Sir, Henry Fowler joined the Committee on taking up the post of Superintendent of the Royal Aircraft Factory, while Commodore Godfrey Paine and Brigadier-General Pitcher served as representatives of the Air Board. Since 1916 the members of the staff of the Air Ministry, the Admiralty, and the Technical Department, Aircraft Section, Ministry of Munitions, who have served on the Committee, have included Major-General Sir W. S. Brancker, the late Lieut.-Colonel Bertram Hopkinson, Brig.-General J. G. Weir, Mr. A. E. Berriman, and Mr. E. C. Given. The Committee is also indebted for much valuable help to other members of the staff of the Technical Department: Lieut.-Colonel (Professor) C. F. Jenkin has acted as Chairman of the Light Alloys Sub-Committee since the retirement of Sir Henry Fowler, in August, 1918, and has served as the representative of that Sub-Committee; Mr. Leonard Bairstow, Lieut.-Colonel Cave-Brown-Cave, Colonel The Master of Sempill, and Major H. E. Wimperis have given much assistance, as well as Major-General Ruck, Vice-Chairman of the Air Inventions Committee. The names of the present members of the Committee, with which is included that of Sir Dugald Clerk, who retired at the end of March last, are printed on p. xiv; the names of the members of the various Sub-Committees are given below.

The detailed consideration of technical questions is now primarily undertaken by Sub-Committees,* which report monthly to the Advisory Committee; Sub-Committees have been

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* The members of these Sub-Committees are as follows:—

Engine Sub-Committee.—Sir Dugald Clerk, K.B.E., F.R.S. (Chairman); A. C. L. Chorlton, C.B.E.; Lieut.-Colonel Mervyn O'Gorman, C.B.; Mr. F. W. Lanchester, M.Inst.C.E.; Dr. T. E. Stanton, F.R.S., representing the National Physical Laboratory; Wing Commander W. Briggs, R.A.F., Commander T. B. Barrington, R.N.V.R., and Captain G. W. A. Brown, representing the Air Ministry; Lieut.-Colonel R. K. Bagnall Wild and Captain R. H. Verney, representing the Aeronautical Inspection Directorate; with the Chairman of the Advisory Committee for Aeronautics (*ex officio*).

Light Alloys Sub-Committee.—Commander C. F. Jenkin, R.A.F. (Chairman); W. H. Dyson, representing the Royal Aircraft Establishment; Professor F. C. Lea, representing the Air Ministry; Captain H. P. Philpot, representing the Aeronautical Inspection Directorate; Mr. A. W. Johns, Chief Constructor, representing the Director of Naval Construction; Dr. W. Rosenhain, F.R.S., representing the National Physical Laboratory; Professor C. A. Edwards; with the Chairman of the Advisory Committee for Aeronautics (*ex officio*).

Aerodynamics Sub-Committee.—Professor J. E. Petavel, F.R.S. (Chairman); Sir G. Greenhill, F.R.S.; Professor H. Lamb, F.R.S.; Mr. F. W. Lanchester, M.Inst.C.E.; Lieut.-Colonel Mervyn O'Gorman, C.B.; Mr. L. Bairstow, C.B.E., F.R.S., and Colonel The Master of Sempill, of the Air Ministry; Dr. T. E. Stanton, F.R.S., and Mr. E. F. Relf, A.R.C.Sc., of the National Physical Laboratory; Captain W. S. Farren, C.B.E.; with the Chairman of the Advisory Committee for Aeronautics (*ex officio*).

Meteorology Sub-Committee.—Sir Napier Shaw, F.R.S. (Chairman); Mr. G. M. B. Dobson; Lieut.-Colonel Harries; Mr. W. H. Dines, F.R.S.; Colonel H. G. Lyons; Mr. A. Mallock, F.R.S.; Lieut.-Colonel Mervyn O'Gorman, C.B.; Professor J. E. Petavel, F.R.S.; Dr. T. E. Stanton, F.R.S.; Mr. G. I. Taylor, F.R.S.; Mr. C. T. R. Wilson, F.R.S.; Major H. E. Wimperis, R.A.F.; with the Chairman of the Advisory Committee for Aeronautics (*ex officio*).

Special Committee on the Electrification of Balloons.—Sir Napier Shaw, F.R.S. (Chairman); Lieut.-Colonel Cave-Brown-Cave; Mr. A. Mallock, F.R.S.; Lieut.-Colonel Mervyn O'Gorman, C.B.; Professor J. E. Petavel, F.R.S.; Lieut. W. H. Rose, of the Air Ministry; Colonel The Master of Sempill; Mr. F. E. Smith, O.B.E., F.R.S., of the National Physical Laboratory; Mr. C. T. R. Wilson, F.R.S.; with the Chairman of the Advisory Committee for Aeronautics (*ex officio*).

appointed to deal with Aerodynamics, Engines, Light Alloys, and Meteorology. The Aerodynamics Sub-Committee was preceded by a Special Committee appointed to consider what is known as Scale Effect, that is to say, the various questions which arise in the application of the results obtained by experiments on models to full scale aircraft. A Special Committee was formed in 1917 to consider the dangers to airships and kite balloons arising from atmospheric electrical discharges and to suggest means of protection; this Committee is still continuing its investigations, and the account of its work given below will, it is thought, be found of interest. The Air Inventions Committee and the Accidents Investigation Committee formed by the Air Ministry also report regularly to the Advisory Committee. In describing the work done it will be convenient to deal in succession with the matters falling within the purview of these several Committees.

Publication of Reports presented to the Committee and its Sub-Committees.—During the earlier period of the War it was considered by the military authorities to be of much importance that the results of research in aeronautics should not reach the enemy. The considerable advances made in the theory and practice of aeroplane stability and control were considered as especially valuable and as giving our constructors and pilots a very material advantage. Special steps were taken therefore to enable manufacturers to secure direct information as to the results of experimental work, while avoiding the printing and circulation of the reports of the Committee. With the immense increase in production which shortly became necessary it was realised that this procedure was impracticable, and arrangements were made for the extended circulation of reports through Section T.5 of the Directorate of Air Technical Services, Royal College of Science, South Kensington, S.W. (now Air Ministry Technical Publications Depôt, 70, Princes Gate), to aircraft manufacturers and departmental officers. Since the Armistice instructions have been given for the publication, with very few exceptions, of the extensive material which has accumulated, and this will be carried into effect with the minimum of delay.

Arrangements have also been made that the individual reports on current work shall in future be published, for general information, as early as possible after they have been approved for issue by the Committee, following careful consideration and amendment by the respective Sub-Committees. It will be realised that caution must be exercised in using the results of current investigations issued in this manner: it is inevitable that it should sometimes be necessary to revise the views reached, and even the experimental results obtained, in the light of later work. Every effort will, however, be made to secure the necessary accuracy in the technical information thus given to the public. The reports will be placed on sale by H.M. Stationery

Office, and lists of new reports published will be furnished periodically to the technical journals.

A large amount of valuable information has been collected by the Technical Department during the War. This is now being prepared for publication by a number of present or past members of the technical staff of the Department under the general editorship of Mr. Leonard Bairstow. It has been arranged that these accounts of the various sections of the work of the Technical Department shall be submitted to the Advisory Committee, and published, with their collaboration, in a new series of reports and memoirs. In addition, it is hoped, in accordance with the recommendations of the Civil Aerial Transport Committee, that steps may be taken for the inclusion in this series of a re-edited and carefully revised account of the earlier researches carried out under the control of the Committee. In the meantime, the annual technical reports of the Committee for the years 1909-14, for which an exceptionally large demand has arisen as a result of the immense expansion which has taken place in the study of aeronautics and the manufacture of aircraft, are being reprinted by H.M. Stationery Office: the first edition has been completely exhausted.

Liaison Work.—As already mentioned, the reports of the Committee were placed in the hands of Section T.5 of the Directorate of Air Technical Services for circulation. Many direct requests for information and copies of papers presented to the Committee have been received from the technical staffs of the Colonial Forces and of our Allies. Continuous exchange of information has taken place, in particular with the American National Advisory Committee for Aeronautics, through the Scientific Attaché to the American Embassy. The work of dealing with these and with urgent requests from the technical staff of the Air Ministry for the more recent papers has been considerable. A large amount of secretarial work has been required also in connection with the Sub-Committees and the editing and issue of the numerous reports received, and an appreciable increase has been necessary in the Secretarial and office staff. Mr. F. J. Selby, who has acted as Secretary to the Committee since its formation in 1909, has had since December, 1918, the help, as Assistant Secretary, of Mr. J. L. Nayler, who has had experience for a number of years in aeronautical research, and has contributed in particular many papers on the later developments of the theory of the stability of aeroplanes, airships and kite balloons.

Equipment for Experimental Work at the National Physical Laboratory and at the Royal Aircraft Establishment.—It was found necessary during the War to increase considerably the facilities for experimental work. In 1914 two wind channels were available at the National Physical Laboratory for experiments on models, four feet and three feet square in section respectively.

During the year 1914–15 a seven-foot channel was completed. In the following year new buildings and equipment were provided, comprising a second 7-foot and a second 4-foot channel, together with offices and workshops. By 1917 the great growth in the work rendered further extension necessary, and provision was made for the erection of a third 7-foot channel, together with a larger channel of special design 7 feet by 14 feet in section. With the increase in the size of aeroplanes constructed, the use of larger models and higher wind speeds became necessary, and it was thought that a channel of this form and dimensions would be of special value for tests on large aeroplane models. The scarcity of labour, however, hindered progress with the buildings, and this channel is not yet completed. It is hoped that it will be in operation within the next few months. The design was based on a large number of experiments with model wind channels; the air current is produced by two airscrews geared to run at equal speeds. The dimensions of the room in which the channel is erected are 150 feet × 70 feet × 40 feet, and a novel method has been adopted of controlling the return air flow.

A 7-foot and a 4-foot channel have also been provided at the Royal Aircraft Establishment, and a second 7-foot channel is in course of erection there. In their main features these channels are of similar design to those of the National Physical Laboratory. Other equipment provided at the R.A.E. or at the National Physical Laboratory for special tests, *e.g.*, that for testing engines at reduced pressure and temperature, is referred to in the supplement.

Aerodynamics.—The discussion of special problems in aerodynamics and of the results obtained in experiments on models is now conducted by the Aerodynamics Sub-Committee. The advances which have been made during the War in the accumulation of aerodynamic data and their application in practice, especially in the construction of high-powered and of large aeroplanes as well as of airships, have been very great. The main aerodynamic principles of aeroplane construction were, however, already clearly understood prior to 1914, and the chief difficulties which constructors have had to surmount have been those necessarily arising from the increasing complexity of engineering design. The estimation in advance, from existing data, of the performance to be expected from a new type of aeroplane of large size and high power, especially as regards its flying qualities in relation to stability and control, is by no means a simple problem, in view of the large amount of special knowledge on which success depends, and it is greatly to the credit of British designers and constructors and speaks much for the care and ability which they have brought into their work that the immense engineering advances made have been accomplished with so little waste of effort and with so small an addition to the fighting dangers braved by the gallant men who have flown the machines.

The most interesting developments, from the point of view of aerodynamic investigation, have probably been those connected with the special manœuvres found possible, and even easy, in the extraordinarily skilful flying exhibited by fighting pilots. Among these may be instanced, as a prominent example of the successful manner in which practice and experiment have progressed together, the very complete and valuable knowledge which has been acquired in relation to the manœuvre known as spinning. This manœuvre, first fully investigated, it is believed, by the scientific staff of the Royal Aircraft Establishment,* engaged in the experimental study of flight problems on the full scale, and immediately taken up and developed by numberless experienced fliers, presents aerodynamically a most complicated problem. The forces brought into play have been closely investigated in the laboratory by experiments on models, the essential features and characteristics of the motion have been very completely calculated from the data so obtained, and the detailed phenomena associated with the motion have all been studied and reproduced in the air, with their varied possibilities and dangers, by the skilled scientific pilots of the R.A.E., with the result that there is now practically no aspect of this complicated motion which cannot be explained and made the subject of calculation. The full bearing and importance of accurate knowledge of this character for purposes of design will only be fully apprehended by the expert: its influence on the development of the aeroplane is by no means limited to the consideration of the particular manœuvre to which it is more especially related. The Committee desire to take the opportunity in this connection to express their very high appreciation of the important services rendered by the investigators of the R.A.E. to our flying forces, in the examination of this and similar problems, with a disregard of personal danger no less admirable than that of their fellow officers in the field. It may be added that the manœuvre produces physiological and mental effects on the pilot, which have an important bearing on the safety with which it can be carried out, and these have also been the subject of careful study.

For a brief résumé of the experimental work in aerodynamics which has been accomplished, reference must be made to the Supplement. It has covered a very wide field. It has been necessarily directed, in the main, to providing the designers and manufacturers of aircraft with exact data immediately required

* Initially a spinning nose dive was a form of loss of control, which usually ended fatally. It was studied by a member of the scientific staff of the R.A.E., who discovered that the aeroplane would recover normal flight easily if the stick were pushed forward, or in the direction contrary to that required for getting out of a nose dive.

for design purposes. Brief mention may be made here of a few of the more important developments.

Many of the changes in aerodynamic structure and design are the direct consequence of increased engine power and speed. With high-powered engines the range of flying speeds was necessarily increased, since landing speeds could not, with safety, be raised appreciably; hence high speed flight must be made at small angles of wing incidence. The form of wing section found to be most suitable for the changed conditions was somewhat different from that used earlier, when the chief aim was to obtain maximum lift for a given air resistance; the new section selected was based on model tests, and has become almost standard for present day aeroplanes.

Examination of the performance of full scale machines using the new form of wing led to some question whether the lift and resistance curves for the full scale wing were completely similar at the small angles of incidence to those for the models tested: this and allied questions formed the subject of enquiry by the "Scale Effect" Sub-Committee, and led to valuable experiments and results relating to biplane wings, though, owing to the difficulty of the full scale experiments necessary for direct measurement, and the many factors affecting the accuracy of the estimation of resistance from performance, the closeness of agreement, or the extent of the departure from agreement, between model and full scale has not yet been fully determined. It is sufficiently clear, from the success with which model results have been applied in design, and the general accuracy of prediction of stresses and performance which they have rendered possible, that the answer to this question when obtained will not affect very seriously the value of model experiments; but this matter of the relation between the wind forces on the model and on the full scale remains one of the most fundamental, and one of the most interesting theoretically, of the problems awaiting solution. It was not possible to give it more attention during the War, but the importance of full scale experiment comparable with that on models must now be clearly recognised and adequate provision for its extension must be made.

Other wing experiments carried out relate to biplane and triplane wings, stress distribution under special conditions of flight, aspect ratio, form of wing tips, effect of "wash-out," best form and dimensions of ailerons, balanced ailerons for large machines, and many other matters. Measurements of the distribution of pressure over the wings of a biplane in flight have been made at the R.A.E.

The experiments on wings have been supplemented by measurements of the wind forces on complete models of a number of different aeroplanes, as well as by many experiments on aeroplane parts, analysis of the resistance of complete aeroplanes and similar work.

Airscrews.—Airscrew theory and practice have made notable progress during the War, following the development of engine power and the use of multiple engined machines, with airscrews in tandem. As is well known, the airscrew when working under the best conditions is a very efficient machine, and retains a large measure of its efficiency even under the widely varying conditions in which it must be used in a high-speed, rapid-climbing aeroplane. The advance here sought has been in the more accurate adaptation of means to ends, to the securing of the best all-round efficiency, which is essentially dependent on a correct airscrew theory as applied in numerical computation. Notable progress has been made in the establishment of such a theory and in its application to airscrew design. Based in part on empirical data, it is yet in all essentials a rational theory, and it will probably be long before further material increase of accuracy can be obtained. A summary of this work has been prepared and will shortly be published. Useful work has also been done towards the production of propellers of variable pitch. The distribution of velocity in the air entering a propeller, and in the slip stream, has been carefully investigated. Mention must also be made of a method devised for determining the thrust of a propeller from measurements of the combined pressure and velocity head in its front and rear: it is hoped this can be applied to determine the thrust of a full scale propeller on an aeroplane in flight.

Stability.—Great progress has been made in respect of aeroplane stability and control both in theory and perhaps still more conspicuously in practice. The main outlines of a working theory of stability are contained in the reports of the Committee published before the War. Experience during the War has firmly established the necessity of their application in design. Moreover, the theory has now advanced greatly beyond the point formerly reached: methods have been developed for the application of stability calculations to the more complicated motions of an aeroplane and from the knowledge gained some of the earlier conceptions have been revised. Theory and practice are indeed so far advanced that further immediate progress would appear to be mainly dependent upon increased accuracy of experiment in the determination of the data upon which all such computation must necessarily depend. Improved methods have been devised, and the work is proceeding satisfactorily. The record is one of steady and continuous progress, and though, with the increasing size of machines, further investigation is constantly demanded, the solution of the problems which arise is in the main a question of time and of the provision of the necessary facilities for experimental work, both on models and on the full scale.

It may be added that the practice has been established, in the trials of new types of aeroplanes at Martlesham Heath, of taking records to determine their longitudinal stability. In respect of lateral stability the advance made has been less complete.

Strength of Construction.—Very closely related to the more strictly aerodynamic questions is that of stress distribution and strength of construction, and this also has necessarily been dealt with by the Aerodynamics Sub-Committee. In their report for the year 1913–14 the Committee, after careful consideration, laid down a basis for the strength factor to be adopted in design recommending tnat the strength required be assumed to be six times that necessary to withstand the stresses occurring in normal horizontal flight. With the great increase in speed and manœuvring power attained during the war a somewhat higher factor was employed in the design of high speed scouts, while for heavy bombing machines a lower factor was found to be sufficient. With the return of peace conditions, sufficient strength will become the primary consideration, and the question will no doubt need to be re-examined, though the stresses to which machines will be subjected in flying for civil purposes will in general be far less than those due to fighting manœuvres.

The determination of the aerodynamic data required for the computation of stress distribution is unavoidably a lengthy and laborious process: it has proceeded steadily to the utmost extent possible among the many insistent demands for experimental work. As an engineering structure the aeroplane presents features differing somewhat widely from those obtaining in structures in which lightness is not so essential, and fresh ground has been broken in the examination of the stress and strain problems arising. New methods of test for application to the actual aeroplane or its parts have also been devised. It is not necessary here to refer to these in greater detail: the volume of work done in this connection has been very considerable, and the publication of an account of the methods and practice of the designs branch of the Technical Department will no doubt be of the greatest value for future design. It has been the practice to make a test to destruction at the R.A.E. of one aeroplane of each new type.

Airships.—The progress in airship construction has probably been relatively greater than that made in respect of the aeroplane: before the War this country was unfortunately behind others in experience in airship work. The advance in the study of airship theory and in the methods of experiment in relation to airships has been less marked. The chief aerodynamic problems requiring to be solved for the airship are, briefly:—To determine the form of envelope under given conditions of design which will have least resistance and to provide data for the calculation of that resistance for full scale airships; to determine the pressure distribution over the envelope under the varying conditions of flight in order to enable the distribution of stress to be estimated; and the complete investigation of the conditions affecting stability and control. At the present time the second of these is probably the one which presents the least difficulty and in regard to which the most complete knowledge is available. The measurement of the head resistance of an airship body, even in the case of a model, has been found to present many experimental difficulties, and the information obtained cannot be said to be yet by any means complete. The step from model to full scale cannot at present be made with any approach to the accuracy requisite. For this, measurements on airships in flight are essential, and though some data have been obtained they can only be regarded as indicating the possibility, and the need, of more systematic investigation. This problem is of far greater complexity and of much wider importance than is perhaps apparent except to the technical expert: the Committee has lost no occasion of pressing that it should be taken in hand even among the difficulties and preoccupations due to war conditions, and the conclusion of the Armistice afforded an opportunity of urging that its investigation should be at once undertaken on an adequate scale while ships and experienced staff were available. Questions connected with stability and control require also to be investigated on the full scale. The expenditure involved will no doubt appear large if the work be regarded from the standpoint of purely experimental research, but a solution of such fundamental problems is of the most pressing importance to enable progress in aircraft construction to proceed on a sure and established basis, instead of by tentative and uncertain steps. In these matters it is imperative to look well to the future.

A programme of experiments has been drawn up, and some of the work is at present proceeding. More complete organisation of this section of the work is, however, desirable and should receive careful attention at an early date.

A very considerable amount of experimental work on airship models has been carried out in the wind channels at the National Physical Laboratory during the past few years for the Department of Airship Production. This work occupies much time and labour, and with the many other immediate questions pressing for solution in relation to the construction of new aircraft it will be realised that the additional channels recently provided have been very much needed. Much improvement has been made in experimental methods, and further progress is to a large extent dependent on the development of full scale research.

In addition to resistance measurements on model envelopes and complete airship models, the wind forces and pressure distribution on airship models at various angles to the relative wind have been determined, and many experiments have been carried out on fins and control surfaces. Important progress has been made in the development of the theory of airship stability.

Mention must also be made of experiments on wind screens in the neighbourhood of airship sheds, and the investigation of methods of mooring airships. A method of mooring for large rigid airships has been devised, in co-operation, by members of the staff engaged on full scale experimental work and of the staff of the N.P.L., which, from the preliminary trials, appears to promise well.

Kite Balloons.—The kite balloon has become of considerable importance for military purposes, and in this connection also there has been a great demand for experimental work, both on models and by full scale trial. The problems presented bear some similarity to those of the airship, but with a number of special features. Model experiments carried out have included measurement of the wind forces and determination of the effect of fins of various forms. The conditions of equilibrium have been investigated, and attention has also been given to stability calculations. The work has been done in close co-operation with the Roehampton staff engaged on full scale work, and important improvements in construction and performance have been effected. Though the volume of work done has been very considerable, it is unnecessary to speak of it here in more detail.

Seaplanes.—In addition to aerodynamic tests on seaplane models, which present no very distinctive features, a large number of tests have been made in the William Froude National Tank on models of seaplane floats and flying boat hulls. A very considerable amount of information has now been accumulated for the guidance of designers, and satisfactory confirmation of the results of the model experiments has been obtained both by full scale trials of seaplanes under their own power and by experiments with seaplanes towed by a destroyer. Experience has thus fully confirmed that new designs may be effectively tried out by means of model tests with great saving of time and expense. An interesting and important part of the work has been the investigation of the stability of a seaplane while planing : special apparatus for these tests was devised, and the equipment for the float tests has been generally improved and developed. Other tank experiments have included the determination of the best form of drogue to serve as a sea-anchor for airships.

Aeroplane Carrier Ships.—Model experiments in the wind channels have been made for the Director of Naval Construction in connection with the design of aeroplane carrier ships. These have related mainly to the flow of air over the alighting deck, and have been confirmed by flying trials. An alternative method of providing for the alighting of aeroplanes on ships has been suggested by a member of the Committee.

Engines.—The central factor in the development of the aeroplane during the War has been the improvement of the power unit. In 1914 the power of engines in common use ranged from about 50 to 75 h.p. Quantity production of engines of five times this power and of low weight per horse power has been one of the most remarkable and successful achievements of manufacturing organisation called for by the War. Progress in the foundry and in the factory has been continuously assisted by the work of the metallurgist and the research engineer. The successful use of aluminium cylinders and pistons has been rendered possible by the researches on light alloys carried out at the N.P.L., the R.A.E., Birmingham University, and elsewhere, with the close co-operation of the foundries experienced in such work. These investigations are referred to more particularly below. In addition, every feature of engine design and performance has been exhaustively studied both by the manufacturer and in the research laboratory : only a great combination of effort could have rendered possible the remarkable results which have been achieved. It is fully realised by everyone conversant with the subject that much remains to be done to render the high-power aeronautical engine as reliable as those used for other forms of locomotion : in no other part of the aeroplane is the strictest economy in the use of material of such vital importance in its effect on speed and weight-carrying capacity. Great as the progress has been, it is in the engine that we must look for the most important developments in the immediate future for civilian flying. Under the guidance of the Internal Combustion Engine Sub-Committee a very large amount of experimental work on engines has been carried out at the R.A.E. and at the N.P.L., while the Engine Section of the Technical Department has laid much valuable information before the Sub-Committee, has kept in close touch with the work, and has indicated the directions in which experiment might be of most immediate assistance. The majority of the more important researches have been conducted at the R.A.E., where special facilities for this work were available.

A great part of the work, and that by no means the least valuable, has been directed to determining the causes of failure in practice. Crank case breakages, crank shaft failures, the burning of valves, piston troubles, difficulties in regard to liners and cooling, improvements in ignition, are among the matters which have been the subject of special investigation.

The problem of engine cooling is one to which much attention has necessarily been given. It is an aerodynamic as well as an engine problem, since the heat dissipation must be effected without raising too much the head resistance of the aeroplane. The solution is thus always a matter of compromise. On air cooling a large amount of work has been done. At the N.P.L. research has been carried out on the heat transmission from smooth and rough surfaces to fluids flowing over them. At the R.A.E. the best methods of applying the laws of cooling in practice to engine cylinders have been investigated: the material to be employed for the cylinders, the best form and spacing for the gills, the design of the cylinders, the effect of enamelling and other factors have been tested on single-cylinder and where necessary on multi-cylinder engines. Much investigation has also been carried out on water-cooled engines: in particular, the radiator problem has been very fully studied both at the R.A.E. and at the N.P.L., and the reports on this work provide tolerably complete information in regard to radiator design.

Another matter to which much attention has been given is the determination of the loss of power with height, *i.e.*, with reduction of air density, and generally the testing of engines under high altitude conditions. Equipment for such tests, after careful discussion by the Sub-Committee, was designed and erected at Farnborough. Means of reducing the loss of power at a height have been investigated, especially the question of super-compression and the use of a blower to maintain the air pressure. Detonation, the effect of increase of the compression ratio, the use of different fuels are other matters to which much time has been devoted. Another research which merits special mention is that carried out at the R.A.E. to determine the working temperatures at various points inside an engine cylinder, a problem of exceptional difficulty.

Continuous research has also been carried out at the R.A.E. and at the N.P.L. on magnetos and ignition. Considerable progress has been made, and it is believed that the results will have much influence on future design. On this and on many engine problems the Sub-Committee has received much assistance from, and has benefited by constant co-operation with, the technical staffs of manufacturing firms.

The advice of the Sub-Committee has been invited by the Air Ministry and by the Technical Department on many important engine problems, and in particular on the selection of engines for production in quantity. In carrying out these duties the Sub-Committee has visited many firms and bodies engaged in engine production, and desires to record its appreciation of the hospitality accorded to it and the ready assistance given by all concerned. Its thanks are specially due to the very efficient technical officers of the Engine Section of the Technical Department.

Light Alloys.—In the study of light alloys for aircraft work two main lines of investigation have been followed. Wrought alloys of high tensile strength are required for rigid airship construction, and for the constructional purposes in aircraft where they can replace steel with a saving in weight. Cast alloys are needed for engine cylinders, pistons and crank cases. The two lines of work are quite distinct. With regard to wrought alloys, much research had been carried out at the N.P.L. prior to the War, in part for the Advisory Committee, in part for the Alloys Research Committee of the Institution of Mechanical Engineers. The most valuable alloy of this type in common use before 1914 was duralumin; this was closely similar in composition to an alloy which had been experimented with at the N.P.L., and was first brought into aeronautical engineering practice in Germany. Since 1914 the Laboratory has been equipped for the investigation of wrought alloys on a semi-manufacturing scale, and the development of duralumin and other high-tensile alloys has been continued with a considerable measure of success. In connection with the work the question of heat treatment is of fundamental importance, and to this special attention has been given. Alloys superior to duralumin in many respects have been produced. With the assistance of the Admiralty and the co-operation of manufacturing firms steps have been taken to introduce the most promising of these into practical use. It will be possible shortly to publish a full account of this work.

The exhaustive study of cast alloys was taken up at the N.P.L. and the R.A.E., as well as at Birmingham and Manchester Universities, and elsewhere, more especially in connection with the work of the Light Alloys Sub-Committee, and the introduction of aluminium alloys into aero-engine construction. The investigations planned by the Sub-Committee have covered the whole ground from the selection by systematic research in the Laboratory of new types of alloys possessing special properties to their use in the foundry for the production of complicated castings in the number necessary for aero-engine production on a war scale. The larger part of the Laboratory work was carried out at the N.P.L. and at Birmingham University; the investigation and removal of manufacturing difficulties at the R.A.E. and at Birmingham, where many foundries collaborated. The properties investigated, in many cases involving new experimental methods, included the tensile, fatigue and impact strength, the hardness and ductility at high and at low temperatures; the effect of continued low temperatures, in which much assistance was given by Sir James Dewar, in the laboratories of the Royal Institution; the conductivity and specific heat at ordinary and at high temperatures; expansion and growth; durability and corrosion; ease of casting and the special conditions to be observed in the production of sound castings both in the Laboratory and in manufacture. Many new alloys have thus been rendered available for various purposes in the future. The metals used include aluminium, copper, zinc, tin, magnesium, iron, nickel, manganese, chromium, vanadium, cobalt and beryllium; aluminium is usually the main ingredient, but alloys with magnesium as a base have also been investigated. Specifications for alloys adopted for practical purposes have been drawn up and issued by the Technical Department, with the assistance and advice of the Sub-Committee. Numerous cases of failure of engine parts under test have been investigated and reported on, not only those of light alloy construction: these have included crank cases, cylinders, pistons, connecting rods, crankshafts and valves. The phenomenon of burning in pistons has been the subject of special study. The lining of engine cylinders by electro-deposition has been investigated as well as other special methods of cylinder construction.

Among other work carried out on aluminium alloys may be mentioned the production of thin sheet to replace fabric for wing covering. A satisfactory procedure for the manufacture of sheet of the requisite thickness has been developed at the N.P.L., and methods of fixing it to the wing have been devised.

Meteorology.—The Meteorology Sub-Committee was appointed in August, 1918. Its functions were to promote co-operation between theory and practice in connection with general meteorological research, and to extend the facilities existing under the earlier arrangement by which a limited amount of research in meteorology had been carried out for the Advisory Committee under the control of the Director of the Meteorological Office. The Committee is also charged with the duty of enquiring into general meteorological problems of importance in special relation to aerial navigation, and of furthering the collection and collation of the information now accumulating at a large number of meteorological stations attached to the Royal Air Force. Special problems concerning the theory and structure of the atmosphere are considered, as well as particular investigations referred for the consideration of the Committee by the Air Ministry, the Admiralty and the War Office.

Among such investigations was one of great interest and importance to which much consideration has been given, in connection with what has been described as a "wind barrage" met with by an airship attempting to cross the sea coast landwards in the neighbourhood of St. Abb's Head. The investigation cannot be considered to be concluded until further observations have been obtained of the wind conditions prevailing in the locality, but it has led to valuable experiments on the effect of eddies on the motion of an airship travelling through them; and it is hoped that further light may be thrown on the matter by the continued study of eddies and eddy motion.

Methods of determining wind velocities at heights have been the subject of careful discussion. Hitherto the method most commonly adopted has been the observation of small balloons by one, or preferably two, theodolites. More recently special methods of observation of smoke puffs from aeroplanes or shell bursts, using mirror or other sights from the two ends of a base, have been employed. The use of theodolite cameras for such purposes has been suggested, and their design is receiving consideration. Instruments have also been devised for obtaining automatic records of temperature, wind velocity and direction, at heights from kite balloons, and for this work kite balloons are now able to ascend to a height as great as 18 or 20 thousand feet. This method clearly offers great advantages, and it is hoped that numerous stations may be equipped for such measurements.

Methods to be adopted in aerial navigation have been considered, especially in connection with the question of wind variation with height. Forms of barometer for height determination have been discussed, and the Committee has put forward the suggestion that in view of the difficulty of obtaining an accurate reading of the atmospheric pressure by any other instrument than the mercury barometer, the design of some form of non-mercurial barometer other than the aneroid, is a matter which merits careful consideration. Experiments have been made for the Sub-Committee on various forms of instrument for the determination and the recording of static pressure in a wind at meteorological stations.

Protection of Kite Balloons from Atmospheric Electrical Discharges.—A Special Committee was formed in August, 1917, to consider the somewhat numerous cases of destruction of kite balloons by fire, apparently owing to electrical discharges, whether due to atmospheric or other causes. Some consideration was given in 1909 to a similar problem in relation to airships, but the number of instances in which airships have been thus destroyed is very small.

A kite balloon is connected to earth by a cable which it is impracticable to render non-conducting and down which even in normal weather an electrical discharge constantly passes, while in special circumstances, and more particularly when a thunderstorm occurs in the neighbourhood, very considerable discharges may take place, and the balloon envelope may be pierced and the gas fired. Reports on a number of cases of accidents to kite balloons have been submitted to the Committee by the Director of Aircraft Equipment, and the circumstances of these accidents have been carefully examined and the possible causes investigated. The conclusion reached was that some means of protecting kite balloons from the effect of atmospheric electrical discharges was necessary. Under the advice of the Committee, and as the result of experiments carried out on their behalf, with the very valuable assistance of one of their members, Mr. C. T. R. Wilson, by the Kite Balloon Section of the Royal Air Force, a form of protecting discharger has been devised for fitting to kite balloons. This is connected with conducting bands encircling the envelope and with the wire cable. This fitting is being exclusively tried in practice, and it is hoped that its use may lead to an appreciable reduction in the number of accidents to kite balloons. A full description of this work has been prepared and will shortly be published. It contains some valuable papers by Mr. Wilson on atmospheric electricity.

Fabrics and Dopes.—The Supplement will be found to contain an interesting account of the considerable amount of work which has been done at the N.P.L. and at the R.A.E. in relation to airship and aeroplane fabrics and dopes, of which brief mention may be made here. The most important investigations with regard to airship fabrics have been those directed to reducing the rate of deterioration, with loss of gas-tightness, in the tropics, and in these considerable assistance has been rendered by the "X" Aircraft Depôt, Aboukir, under the superintendence of a former member of the N.P.L. Staff. It has been established that the deterioration is due almost entirely to the actinic radiation of sunlight, and that considerable protection can be afforded by introducing pigment into the outer layer of rubber. No satisfactory means of reproducing the effect of the sun's rays with sufficient intensity in the laboratory has yet been found. Methods of fireproofing have been investigated.

In relation to the permeability of fabrics, a method of test devised by Dr. Shakespear, of Birmingham University, has been found very valuable for much investigation and routine work. The permeability of fabric by helium was determined at the N.P.L. at the request of the Admiralty Board of Invention and Research.

Methods of testing the strength of aeroplane fabrics had been worked out with some completeness at the N.P.L. prior to the War, and these have since been made the basis of the standard specifications for the fabrics in use. From the experience gained during the War it would appear that these afford an ample margin of safety even for fabric much damaged by bullet wounds or shrapnel. The use of "calendered" fabric has been investigated at the R.A.E.; and cotton fabrics, as well as coarser varieties of linen, have been found suitable for the covering of wings.

The deterioration of aeroplane fabrics, especially in the tropics, has been fully investigated. A pigmented dope, first prepared at the R.A.E., has been very satisfactory in reducing the rate of deterioration of the fabric and the loss of tautness. Special methods of measuring tautness have been devised. Valuable work has also been done in the investigation of the inflammability of fabrics under conditions approximating to those obtaining in flight. Special attention is being given to means of reducing the risk of fire in aeroplanes owing to spilt petrol or oil.

Difficulty was experienced in the earlier period of the War owing to the shortage of the materials then ordinarily employed in the manufacture of dopes, and extensive investigations have been carried out as to the suitability of various substitutes, some of which have been found superior in many respects to the materials previously used. Attention has been given to the use of other materials than fabric for the covering of aeroplane wings.

Bombs and Bomb-dropping.—Much attention has been devoted to the study of bomb trajectories, the determination of the most suitable design of bomb, and to sighting instruments for use in bomb dropping. Model tests and calculations have been carried out at the N.P.L., while a large amount of full-scale experimental work, in addition to calculations of trajectories and the design of sights, has been accomplished by the branch of the Department of the Director of Air Services dealing with this work (later the Air Ministry Laboratory, South Kensington).

Assistance was given by Professor Karl Pearson in the preparation of numerical tables for the computation of bomb trajectories. Some interesting experiments were made on the terminal velocities of bombs dropped into water, as in attacking submarines.

Mention may also be made here of assistance given by the Committee in relation to the attack of aircraft from aircraft.

Special Engineering Work.—Investigations of an engineering character have also been carried out at the N.P.L. in connection with a number of questions not falling under any of the preceding heads. These include fatigue tests of flexible cables and their attachments, vibration tests of cables and raf-wires, tests of turnbuckles, tests of timber in connection with its use for aeroplane construction, including fatigue tests, &c. Fatigue tests of wing spars have also been made, and compression tests of struts.

Instruments.—The development of the numerous instruments required for special purposes on aeroplanes has been dealt with especially at the R.A.E., as well as at the N.P.L., and by individual members of the Committee. The aeroplane compass was the subject of much investigation at the R.A.E., conducted earlier by the late Dr. Keith Lucas and continued, after his death in a flying accident, by other members of the R.A.E. staff. Much assistance in this work was given by Sir Horace Darwin, to whom the country is indebted for many other devices in connection with flying, among which may be mentioned those for indicating departure from straight horizontal flight. An accelerometer for use on aeroplanes was developed at the R.A.E. with the assistance of Dr. G. F. C. Searle. A special type of petrol flowmeter designed at the Central Flying School gave very satisfactory results under test at the N.P.L. Sighting instruments and rangefinders have also been specially developed at the R.A.E.

A special form of yawmeter, employed, in particular, for determining the direction of the local air current in a wind channel at any point in the neighbourhood of a model, and a hot wire anemometer, for exploring the distribution of velocity, have been devised at the N.P.L.

Air Inventions Committee.—The Air Inventions Committee was appointed by the Air Ministry in September, 1917. To secure co-ordination of the work it reports periodically to the

Advisory Committee; its Chairman, Sir Horace Darwin, is a member of the Advisory Committee, and its Vice-Chairman, Major-General Ruck, has regularly attended the meetings of that Committee.

The names of the present members of the Air Inventions Committee are given below.* During the past year, Sir Dugald Clerk, Mr. F. W. Lanchester, and Mr. J. P. Millington have resigned their membership, while Mr. E. C. Given, Director of Aircraft Production; Major J. Heckstall-Smith, of the Board of Invention and Research, Admiralty; and Brigadier-General E. M. Maitland, of the Admiralty Airship Department, have joined the Committee in order to ensure closer co-operation between this Committee and their respective departments. Representatives of other branches of the Technical Department and of other Departments concerned, as well as of the Society of British Aircraft Constructors, attend meetings, or are otherwise consulted on relevant inventions.

The duties of the Committee include the examination of all inventions received at the Air Ministry; development, trial, experiment, and reporting on these inventions; the consideration of all applications for patents received from members of the R.A.F. and the technical staff of the Air Ministry, with the drawing up of specifications and plans and all other matters connected with such patents; the investigation of claims from inventors in respect of the Government use of their inventions, and the preparation of all cases of award from inventors in connection with aircraft.

The number of inventions received since the formation of the Committee is 7,816; the most valuable of these have been described in the reports made to the Advisory Committee. Much useful work has been done in the trial and development of designs which appeared to present valuable features.

Since the date of the Armistice the number of inventions received has appreciably diminished, and their tendency is naturally in the direction of the development of civil aerial transport rather than towards war purposes.

Accidents Investigation Committee.†—This Committee was

* The members of this Committee are as follows:—

Air Inventions Committee.—Sir Horace Darwin, K.B.E., F.R.S. (Chairman); Major-General R. M. Ruck, C.B., C.M.G. (Vice-Chairman); Mr. L. Bairstow, C.B.E., F.R.S.; Professor H. L. Callendar, F.R.S.; Sir R. T. Glazebrook, C.B., F.R.S.; Major A. V. Hill, O.B.E. (M.I.D.); Lieut.-Colonel B. M. Jones; Professor C. H. Lees, F.R.S.; Professor J. E. Petavel, F.R.S.; Major G. I. Taylor, F.R.S.; Major H. E. Wimperis, O.B.E., R.A.F. (Technical Department); Mr. E. C. Given (Airship Department, Admiralty); Major J. Heckstall-Smith (B.I.R.); Brig.-General E. M. Maitland, D.S.O. (Airship Department, Admiralty).

† The members of this Committee are as follows:—

Accidents Investigation Committee.—Lieut.-Colonel Mervyn O'Gorman, C.B., D.Sc. (Chairman); Professor J. E. Petavel, F.R.S.; Mr. G. B. Cockburn, O.B.E.; Mr. Leonard Bairstow, C.B.E., F.R.S.; Mr. [illegible] Pippard; Secretary:—Major Fulton.

appointed in January, 1918, to advise as to questions arising in relation to accidents. It reports periodically to the Advisory Committee and makes recommendations as to experimental work required to elucidate the causes of accidents under investigation. The work of the Accidents Committee is felt to be of the highest importance and value, and all possible assistance has been rendered towards furnishing any data found to be necessary in examining the conditions occurring in connection with special accidents. In particular, the staff of the Royal Aircraft Establishment engaged in carrying out full scale research have reproduced in the air special conditions of flight thought to have led to types of accidents investigated, and with the aid of the information so obtained and the results of model experiments, it has been possible in some important instances to obtain a complete explanation of the circumstances leading to these accidents, and to take the necessary steps to prevent such circumstances arising. Reference may be made, in particular, to conditions occurring, in the case of some aeroplanes, in connection with spinning, of which mention has been made earlier, and in inverted flight. The Committee desire to place on record their appreciation of the gallantry and skill exhibited by the members of the Royal Aircraft Establishment Staff who have assisted in this work, which has undoubtedly contributed to the saving of many lives. Valuable information has also been given, in many instances, by other pilots of the Royal Air Force.

The Accidents Committee has been in close touch with the Designs Branch of the Department of Aircraft Supply, thus securing that information as to any structural modification thought to be desirable should reach those in control of design without delay.

As already indicated there is no doubt that information of the greatest value has been secured through the investigations of the Accidents Committee and it is considered to be of the utmost importance that this work should be continued and extended.

Provision for Future Research.—Reconstruction and reorganisation, alike in methods of research and of manufacture, are among the problems of primary importance which have arisen with the termination of the War. The Advisory Committee for Aeronautics was appointed in the spring of the year 1909 and has now completed ten years of work, which the Committee venture to hope will provide a record of some importance in the early history of aeronautics and much of which, it may not unreasonably be thought, will remain of permanent scientific value. Of eleven members of the Committee as originally appointed nine remain on the list of members printed in the present report. The first representatives of the War Office and the Admiralty have been replaced by other officers of the Departments now responsible for aeronautical work. The continuity thus maintained has not been without its value. The need of progress in aeronautical science and technology, in education and research is now universally recognised as much more pressing, the demand for the greatly increased expenditure required is now much more readily granted, in this as in other fields of investigation, than it was in 1913. It has taken a European war to give us a national Department of Scientific and Industrial Research. More complete organisation and co-ordination of research in aeronautics for civil and military purposes will be needed for future work. The Committee feel that it is appropriate to conclude this review of their activities during the War by urging and insisting once again on the essential and immediate importance of greatly increased activity in the investigation of the new problem of flight, which is undoubtedly destined to exercise an ever-increasing influence on the future history of the world. Knowledge of the fundamental principles of the science of flight is still at the beginning, the developments which have taken place in their application, even during the last five years, are relatively small. The expenditure now incurred in scientific and industrial research in aeronautics is utterly insignificant in comparison with the sums expended, and which will be required, in the manufacture of aircraft for the purposes of civilian flying and for defence. Wise forethought, an instructed economy, demand that greatly increased facilities be provided without delay for the study of the scientific and technical questions awaiting solution, to minimise wasted effort and to lay down a sure foundation on which succeeding generations may build with security. It is not to be expected that industrial progress will be very marked during the next few years: the determination of flying routes, the preparation of aerodromes over the whole of the world, the study of meteorological conditions, these are matters to be dealt with on so large a scale that a lifetime will be required to show the progress made in the proper perspective. There is the more need that we should not be sparing in expenditure on work for which the returns will perhaps not be immediate, but which will surely repay its cost a thousandfold to the Empire which our sons and daughters will rebuild.

The Committee desire to put on record their special acknowledgment of the work of their Secretary and Assistant Secretary in the preparation of this report. They have been indebted to these gentlemen for very valuable help during a number of years. The present report gives some idea of the amount of secretarial work involved, and the Committee are glad to take this opportunity of thanking Mr. Selby and Mr. Nayler for the great services they have rendered.

Signed on behalf of the Committee,

R. T. GLAZEBROOK,

CHAIRMAN.

August 13th, 1919.